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BUREAU OF ENTOMOLOGY

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THE MOUNTAIN PINE BEETLE IN SUGAR PINE

SEASON OF 1933

Preliminary Report

By
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U. S. Bureau of Entomology

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THE MOUNTAIN PINE BEETLE IN SUGAR PINE

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INTRODUCTION

In recent years the gradual and increasing aggressiveness of the mountain pine beetle, Dendroctonus monticolae Lec. in valuable sugar pine stands of the Sierra Nevada mountains has been of particular concern to National Park and Forest Service officials and forest entomologists. Widespread damage to magnificent timber of outstanding commercial and esthetic values in the Central Sierra Region, embracing the Stanislaus, and Sierra National Forests and Yosemite, General Grant, and Sequoia National Parks had reached a peak in 1932, following which large sums of money were spent by the Federal Government in combatting further destruction.

Recognition of the gravity and importance of this problem by the Forest Insect Division of the Bureau of Entomology resulted in studies which were begun at the institution of J. M. Miller of the Berkeley station late in 1932 and which were continued through the summer season of 1933. Problems of greatest value to the establishment of well directed control policies were considered in preliminary studies; (1) extent and character of damage; (2) seasonal history, habits and host relationship of the mountain pine beetle; (3) the importance of other insect enemies of sugar pine; (4) the possibilities for improvement in control technic. During this period, considerable information was obtained on parasitic and predacious enemies of the mountain pine beetle and other associated species found under the bark. The results of investigations presented in this preliminary report are primarily concerned with the seasonal history of the mountain pine beetle and host relationship. Control methods are discussed, but as yet certain experiments on control are still in progress and will be reported later.

These investigations were carried on by the writer assisted by Albert Wagner and E. F. Wohletz. The working areas from which basic data were obtained are located near Bass Lake on the Sierra National Forest at elevations between 4,500 and 7,000 feet where infested sugar pines furnished an abundance of material for study. Further information was secured in Yosemite National Park and the southern part of the Sierra National Forest, chiefly from surveys to determine the extent of injury and history of infestations.

EXTENT AND CHARACTER OF DAMAGE

Prevalence

Figures which show the destructiveness of the mountain pine beetle over the past ten years are rather meagre, and not until four years ago were regular surveys begun on permanently located sample plots for the purpose of securing annual records on representative areas. The figures already secured have been of great value in determining control policies. Projects carried out in the Sierra National Forest between 1931 and 1933 and in Yosemite National Park during 1932 and 1933 were started partly as the result of trends toward epidemic conditions shown on plots included in the surveys, and partly because of observed increases in the number of fading trees throughout sugar pine stands (see Photo 1 (8551)). In each project, however, the treatment of sugar pine was incidental to the main purpose of reducing epidemics of the western pine beetle in ponderosa pine. But as they were started it was soon found that the losses to sugar pine were enormous since most of the trees killed were of great size and volume.

In 1932 epidemic conditions were apparent in the finest stands of sugar pine generally over the Central Sierra region. The following figures, which were obtained on three representative plots from 1931 to 1933, give some idea of the losses and tendency toward epidemics but are not truly representative of all areas. Plot 12 exaggerates the condition whereas Plots 9 and 14 under-estimate it.

TABLE I

Sugar Pine Losses on Three 320-Acre Plots

Plot #	Acres	Annual Losses								Percent of Stand Volume
		1931		1932		1933		Total		
		Trs	Volume	Trs	Volume	Trs	Volume	Trs	Volume	
9 Sierra	320	1	3,370	12	37,650	5	30,500	18	71,520	5
12 Sierra	320	8	33,870	31	109,700	15	88,050	54	231,620	10
14 Yosemite	320	2	12,540	14	66,080	8	46,530	24	125,150	3

Figures showing volume and number of sugar pine killed by D. monticolae and treated in control projects on the Sierra National Forest and Yosemite National Park during 1933 are presented in Table II which follows. They are more representative of the actual conditions found, and show what enormous losses had been built up at the time control projects were instituted.

TABLE II

Treated Volume of Sugar Pine Killed by D. monticolae*

Area	Location	Acres	Treating Date	Trees	Volume	Vol. per A.
Fence Meadow	Sierra NF	11,092	Spring-1933	425	2,418,050	227
Wawona Basin and F.S.lands	Yosemite	12,041	" "	415	2,204,870	183
Wawona Road	"	10,673	" "	301	1,798,870	168
Akerson Mdws.	"	3,591	" "	204	1,120,340	312
Aspen Valley	"	4,779	" "	186	1,381,600	289
Crane Flat	"	2,280	" "	79	555,990	244
Wawona Dome	"	2,640	" "	74	468,340	177

A striking comparison of losses in ponderosa pine treated on the same areas during the same period, is shown in Table III. Although the number of trees treated was considerably larger than sugar pine, the volume amounted to less than half in most cases. This is all the more significant when the primary objective of these projects was western pine beetle control.

TABLE III

Treated Volume of Yellow Pine Killed by D. brevicomis

Area	Trees	Volume	Vol. per A.
Fence Meadow	1,013	1,914,810	173
Wawona Basin and F.S. lands	746	1,394,200	116
Wawona Road	426	819,770	75
Akerson Meadows	225	317,820	61
Aspen Valley	157	275,310	58
Crane Flat	8	25,500	11
Wawona Dome	42	122,880	46

Character

Dead or dying sugar pines resulting from attacks of the mountain pine beetle are set off in contrast to normal green trees by certain distinguishing features which enable the trained observer to recognize them soon after the beetle has become established. The most outstanding feature is reflected in the rapid change in foliage color from pale silvery green to yellowish green, then sorrel to bright reddish brown, and finally dark reddish brown. These changes are most rapid during the summer season when

* These figures were taken from control reports by C. A. Gustafson (Sierra) and Emil Ernst (Yosemite). Separate Reports of Projects carried on during the spring, 1933.

from one month to six weeks elapse from the first sign to final bright reddish brown color. Reddish brown pitch tubes, characteristic of Dendroctonus beetles are also conspicuous on the bark and in bark crevices of the infested part of the trunk, where they are scattered fairly evenly over the entire circumference of the infested length. They are not found ordinarily in the basal part of the trunk until the tree has been killed above, hence foliage color is the most reliable index of an attack.

The mountain pine beetle always attacks the main trunk and frequently large branches over six inches in diameter, and usually the initial attacks are made in the upper third to fourth of the trunk (See Photo 2 (8556)). Following the death of the top, attacks are extended in the green areas below until the entire tree is dead, (See Photo 3 (8557)). It frequently takes three to four separate attacks, carried over as many years, to complete the death of many of the largest trees. Pole-sized trees and those with diameters less than 40 inches D.B.H. are often killed by a single invasion over the entire length of trunk.

Trees which are gradually killed by several invasions of beetles, reflect this condition by various gradations of foliage color, from top to the bottom of the crown, while those attacked by a single invasion fade fairly equally over the entire crown. The foliage of dead trees gradually darkens and after a period of two to three years drops to the ground, leaving the trees standing as snags. (Photo 4 (2637D))

Classification

As already indicated, the length of trunk infested by D. monticolae is subject to considerable variation, and this is manifest externally by the foliage adjoining the part of the trunk affected by the beetle. Detailed data on the actual infestations found beneath the bark along the infested length have made it possible to classify each dead or dying tree into one of six distinct types. These types are based on complete stem analyses made on 84 trees varying in diameter from 20 to over 80 inches D.B.H.

Figure I is a graphic illustration showing the distribution of D.m. In addition Ips confusus and flatheads, Melanophila gentilis are indicated as a cause of death to the tops of certain of these types. Although secondary as a rule, Ips and especially flatheads are the cause of much primary damage in the lower altitudinal range of sugar pine stands, discussed later in this report. The frequency of each type among the 84 analyzed trees is shown by a column graph in this figure in percent of the total volume. The number of trees in each type is indicated by circled numerals under each column. A brief description of each type follows:

Type 1. Killed in the top 20 to 30 feet and abandoned by Ips confusus or/and flatheads, either before or after an invasion lower down by the mountain pine beetle; the next 1/4 to 1/2 of the trunk length with an abandoned attack of D. monticolae; the next 1/4 to 1/3 of the trunk with a brood of D. monticolae; the final 20 to 40 feet green and unattacked.

Type 2. This type is similar to type 1 but differs in that the second D. monticolae attack extends to the base, leaving no green unattacked areas.

Type 3. Killed in the top 1/4 to 1/3 and abandoned by D. monticolae; the next 1/2 to 3/4 of remaining length of trunk with brood of D.m.; the remaining 20 to 40 feet of basal trunk green and unattacked.

Type 4. This type has a single attack of D. monticolae with brood extending from the top to within 15 to 30 feet of the base which is green.

Type 5. Top 20 to 30 feet killed by Ips or/and flatheads with broods present, attacked after earlier invasion of the trunk by D. monticolae; remaining length of trunk with complete attack of D. monticolae and broods present.

Type 6. Top 20 to 30 feet green with no attacks; remaining length of trunk infested with broods of D. monticolae.

SEASONAL HISTORY

Cycle of development

Two complete generations are produced each year by the mountain pine beetle in sugar pine stands found in the Central Sierra region. A partial third generation is frequently produced if warm spring and fall conditions prevail. Adults are found in flight on warm days at any time from March 15 to November 15, but in large numbers only during late June, July, and early August, when the main summer attack is made. Attacks occur constantly throughout the flight period, and a great deal of variation in brood stages is found at any time during the year. Individual trees often have broods in stages from eggs to adults. This is especially true of trees attacked early and late in the flight period when there is an insufficient number of beetles at one time to make a complete attack. For this reason scattered attacks are commonly found on top-killed or dying trees.

Figure 2 is a graphic representation of the number of seasonal generations developed by the mountain pine beetle in sugar pine stands on the Sierra National Forest. This chart is based on records taken from close observation of 35 trees during the complete cycle from attacks and eggs to new adults and emergence. Overwintered broods and broods established at intervals throughout the summer months were included in data which were taken from trees attacked under field conditions, trees felled as trap logs, and trees which were attacked by adult beetles admitted to insect tight cages enclosing a portion of the trunk.

The overwintering brood stages occur in all ages of larvae, pupae, and new adults. These stages are represented by two groups on the chart; Group I consists of larvae from 0 to 3/4 grown and Group II is composed of pupae and adults. Group I requires the warm spring period in which to complete development of the larval stage, while Group II is ready to emerge and start a new attack and generation as soon as warm spring temperatures stimulate growth and activity. Thus it frequently happens that a first seasonal

generation is started during the latter part of March and April, often earlier, which is completed at the time Group I is ready to begin a new cycle of development during the latter part of June, throughout July, and part of August. This is designated Generation "A" on the chart. Then, with the first seasonal generation produced from broods which overwintered in the larval stage, a second generation is produced from broods which overwintered in the pupal and adult stages by the emergence of Generation "A". Thus, Generation "B" is the first seasonal generation developed from Group I, and the second seasonal generation developed from Group II. Generation "C" follows as a result of the emergence of Generation "B". This is the second seasonal generation from Group I and the third seasonal generation from Group II, developed during the latter part of August, through September, October, and part of November. If warm fall temperatures prevail the oldest broods of Generation "C" complete development and emerge to start a new generation designated as "D", a third generation developed from Group I.

The following schedule was found for broods established between September 1932 and August, 1933 and is carried further to predict the broods to be found in the spring of 1934.

Brood Started		Brood Emerged	
Year	Month	Year	Month
1932	September	1933	June, July
1933	March, Apr.	1933	" "
1933	May	1933	July, Aug.
1933	June	1933	September
1933	July	1933	Oct., Nov.
1933	August	1934	Mar, Apr, May

Duration of stages

The period required for the completion of each developmental stage is dependent on the prevailing bark temperatures directly affecting each individual. For this reason a much longer time is necessary to produce a generation during the cold winter season than during the summer. This is especially true of the larval stage which depends solely on feeding to complete development, but when the temperature is too low, feeding ceases and is not resumed until favorable temperatures appear.

In the following table data are presented which show the average time required for each developmental stage during the summer and winter seasons. These figures are based on actual close records followed on twenty-five trees under the two conditions. Fifteen of this number were trees which were caged for the purpose of controlled rearing, in which adult beetles were forced to attack. Records from ten additional trees were obtained from attacks made naturally on green standing trees and from green trees felled to attract beetles in flight. No essential difference in development was found under any of these conditions.

TABLE IV

Average Development Period in Days for Each Stage

Season	# Trees	Egg Incubation	Larval	Pupal	Total Period
Overwinter	9	12.1	260.0	12.5	284.6
Summer	16	9.0	32.9	9.3	51.2

Habits

(1) Attacks and eggs. Green trees are attacked by adult beetles during the flight period. No great number of adults are found at one time but within a period of a few days after a tree has been selected, many beetles are found in the process of constructing the characteristic pitch tubes on the outside of the bark. On warm days the beetle activity on newly attacked trees is definitely audible from within a few feet; a ticking sound is caused by bits of bark picked away. But cutting in and removing the bark to expose the cambium layer, the egg galleries of the beetle are found, which are grooved rather deeply in the inner phloem layer. These extend vertically as a rule, but do not always run true to form, for they are commonly found winding to and fro without definite pattern, (See Photo 5). The more typical gallery is curved at the bottom for about 2 to 3 inches and runs vertically from the curve to 24-30 inches when complete. With the extension of every gallery, all borings and frass material is packed behind the beetles at work.

The extension of galleries is accomplished entirely by the female while the role of the male is primarily fertilization. Two beetles are always found in each gallery under construction. The male is usually 1 to 3 inches behind the female and commonly faces her, but frequently is found facing the entrance hole. Males have often been found excavating the so-called "ventillation" holes, which are nearly always found in sugar pine to be depressions at irregular intervals along the dorsal side of the gallery, and which the writer believes serve to enable the beetle to reverse direction of travel.

With the extension of gallery by the adult female, small indentations or pockets are made at irregular intervals along each side. In each pocket from one to four eggs is deposited in tiny nitches made large enough to accomodate a single egg.Following each deposition, frass material is packed tightly behind, apparently a protective measure against invading enemies, and a purchase for newly incubated larvae. Egg gallery construction and deposition of eggs are completed from four to six weeks following attack, at which time it is the habit of many of the parent adult beetles to emerge and re-attack other green trees.

(2) Emergence and re-attack. The extent to which this is done

is not known definitely in sugar pine, but it has been demonstrated to be of economic consideration in western white pine *. In an experiment conducted on sugar pine during the 1933 season, only a small proportion of the adults emerged, following a five week period of attack and no difference was found at the termination of the experiment after two months. Cages 28, 29, and 30 were used in this experiment. Cage 28 consisted of two trees, each 8 inches in diameter, standing side by side. (Photo 6) Each tree was caged, and 300 new black adult beetles, collected from their pupal cells in overwintered brood trees, were admitted to one of the cages, where they established normal successful attacks. Two weeks following attack, both cages were joined into one insect tight cage surrounding ten feet of the basal part of the trunks of both trees.

Cages 29 and 30 were essentially the same. Both used logs two feet long, two logs ultimately in each cage. One set of logs was paraffined on the ends to prevent loss of moisture. At the start 160 black adult D.m. collected from pupal cells in an overwintered brood tree were admitted to each cage with one log. After a two week period, duplicate unattacked logs were placed in each cage with the attacked logs. Table V gives the results of this experiment. Normal broods developed to maturity in all cases.

TABLE V

Attacks Made By Re-emerged Beetles

Cage #	D.m. admitted	No. of original attacks	No. of attacks by re-emerged D.m.	Number of days between original attacks and attacks by re-emerged beetles
28	300	75	5	32
29	160	43	6	34
30	160	39	4	41

(3) Larvae. D.m. larvae are essentially no different in appearance from other Dendroctonus larvae. With the incubation of eggs, they begin feeding immediately, working in small channels at right angles to the egg gallery, the channels increasing in size with larval growth and development. Most of the brood in this stage spends the entire feeding period along the inner phloem layer next to the wood. Individuals occasionally mine for a distance into the bark, this factor apparently depending on bark thickness and available food supply. When mature, each larva hollows out a cell, usually between the bark and wood, (Photo 7) where it remains in a quiescent state to complete the prepupal and pupal stages. The number of larval ecdyses was not determined.

Brood Statistics

In Tables V, VI, and VII which follow, figures are presented which show a wide variation in number of broods in different stages of

* Bedard, W. D. Additional Information Concerning the Biology and Habits of the Mountain Pine Beetle in Western White Pine-Unpublished Report.

development per unit of bark area, a wide range of abundance in the same stage of development, and a reduction in all cases of brood toward the more advanced stages. They were obtained by making complete counts on a number of infested trees during the 1933 season. The broods produced in trees which were caged during the fall of 1932 were very much lighter than any of the others, the cause of which was due to heavy parasitism in the thin-barked trees. One parasite, Coeloides sp., was particularly abundant.

TABLE VI

EGGS

Tree #	Attacks	Egg Channels in inches.	Eggs	Eggs per inch of channel
Cage 17:	106	373	427:	1.14
33/6	9	156	443:	2.80
33/8	13	336	389:	1.12
33/9		131	426:	3.20
33/5		308	1483:	4.81

TABLE VII

Larvae, Pupae, Adults

1932 Broods

1. Caged trees-forced attacks

Tree #	Date of analysis 1933	Bark area Sq.Ft:	Attacks	Egg channels in inches.	Larvae 0-½	Larvae ½-1	Pupae	N.A.	Tot.	Br. per Square Foot	Br. per in of gallery
Cage 3:	July 5	3.3	7	290	4	5	6:	87:	101:	30.6	.34
		2.6	6	168	0	1	1:	12:	14:	5.3	.08
" 5:	" "	3.6	9	462	17	61	41:	31:	150:	41.6	.32
" 7:	" "	4.5	10	490	136	100	76:	85:	397:	88.2	.81
	" "	3.5	11	448	62	6	21:	61:	150:	42.8	.33

2. Standing trees attacked naturally

32/37	June 25:	8.0	45	1,344	122	131	78:	390:	723:	90.4	.53
32/38	May 19	12.0	94	1,560	664	1050	8:	360:	2082:	173.5	1.33
32/41	June 6	4.0	14	600	0	66	269:	95:	430:	107.5	.72
32/42	" 7	8.0	34	1,104	471	510	113:	6:	1100:	137.5	1.00
32/43	" 9	4.0	21	672	0	96	484:	10:	590:	147.5	.87

1933 Broods

1. Caged trees-forced attacks

Cage 18:	Aug. 31:	1.2	5	228	21	60	31:	44:	156:	130.0	.68
" 19:	" "	4.3	25	684	75	158	82:	98:	413:	96.0	.60
" 20:	" "	6.0	33	936	88	214	77:	89:	468:	78.0	.50
" 23:	" 30:	5.5	22	576	199	381	169:	95:	844:	153.4	1.46

2. Standing trees attacked naturally

33/6	July 12:	2.0	12	264	32	67	75:	78:	252:	126.0	.95
33/7	" 11:	6.6	78	1,176	16	60	301:	540:	917:	138.9	.77
33/8	" 14:	2.0	12	360	0	28	72:	95:	195:	97.5	.48
33/11	" 26:	4.0	18	648	162	45	34:	87:	328:	82.0	.50

TABLE VIII

Emergence.

Tree #	Sample	Bark Area Square Feet	Attacks	Length of egg galleries inches	Emergence period days	New Adults	Emergence per Square Foot
Cage 3	Log #1	4.0	7	228	21	14	3.50
" "	" #2	2.4	3	120	1	1	.04
" 5	" #1	4.0	8	288	32	123	30.75
" 7	" #1	5.6	13	516	49	136	24.29
" "	" #2	4.00	11	360	25	22	5.50
32/39	South	10.00	--	---	51	79	7.90
"	North	10.00	--	---	49	147	14.70
32/44	West	10.00	--	---	13	58	3.80
32/45	East	10.00	--	---	48	26	2.60

Relation between temperature and brood development

When the temperatures affecting brood development fall within the optimum range there is little or no difference in the period required to produce a generation of D.m. adults, regardless of 10 to 15 degrees difference in average daily maximum and minimum temperatures. This was conclusively shown in an experiment to determine whether more generations were produced in lower than in the higher altitudes of sugar pine stands.

Cages 21 and 23 were used; cage 21 was situated at approximately 4200 feet, while cage 23 was built around a tree at 7,000 feet elevation. Both elevations represent the extremes of the sugar pine range on the Sierra National Forest. The trees selected for each cage were slow growing and about 8 inches. D.B.H. The cages were of the screen cylinder type, constructed around the basal 10 feet. Eleven hundred D.m. adults were admitted to cage 21 while only 500 were admitted to cage 23 between June 20 and 23. All adults were removed from overwintered brood trees. Thermograph records of air temperatures were taken from each situation during the entire period of development. The daily maximum and minimum temperatures taken from these records are charted (Figures 3 and 4), and show from 10 to 15 degrees difference under each situation. Table IX, which follows, shows that the development was nearly equal under each situation.

TABLE IX

Period of Development--Cages 21 and 23.

1933

Cage #	# adults	First attack	First eggs	First larvae	First pupae	First adults
21	1,100	6/21	7/1	7/12	8/14	8/21
23	500	7/3	7/10	7/24	8/20	8/20

Other factors being equal, an explanation for the same rate of development is found by applying the number of hours of effective temperature to development. Temperatures between 50 and 70 degrees Fahrenheit are evidently most important, since in each case the number of hours exposure is nearly equal. Temperatures about 70 may have actually retarded development, which is a plausible explanation for the slightly longer period required for broods in cage 21. Table X shows the number of hours air temperature above 40 degrees in each situation during the developmental period.

TABLE X

Hours of Highest Air Temperatures--July 1 to Aug. 21

Degrees Fahrenheit	Hours Elev. 4200	Elev. 7000
50-59	1224	1211
60-69	1128	855
70-79	787	319
80-89	295	34
90-97	29	0

Relation between the growth rate and success of attack

The success of D.m. attacks is dependent to a certain extent on the condition of growth in a given tree. Slow growing trees are much easier to overcome, but it by no means is an indication that they are attacked, for so far it has been found that very little if any correlation exists between growth rate and trees killed under natural field conditions.

The graph, Figure 5, shows a 14-year comparison in growth between 25 trees which were killed during the summer of 1932 and 25 green check trees, selected carefully in all details. The growth curve of each group is nearly alike that it is hardly possible to link growth rate with beetle selectivity. The green trees were actually growing slower until 1925 when the curves of both groups came more nearly together and remained so until 1929, when a drop occurred in the beetle killed group. The divergence between growth rates of each group widened slightly from then until the ultimate killing, but the difference was not great enough to be of much significance. Complete records taken from each of the insect killed trees revealed that they were entirely killed during the year 1932 and that there had been no gradual weakening over the few years preceding death, which might have been reflected in the slower growth rate.

From data obtained by caging trees of varied rates of growth, it wasfound that with a given number of beetles per square foot of area attacked, it was much easier for them to become established in slow growing trees than in either moderate or rapid growing trees. All slow growing

trees were overcome and completely killed within a short period, while varying degrees of resistance were shown in the medium and fast growing groups. In Table XI, which follows, 12 trees are compared; 4 trees belonging to each group.

TABLE XI

Comparison of Fast, Medium, and Slow Growing Sugar Pines in Relation to Attacks by D.m.

Cage #	D.B.H.	Caged: D.m. per: area: sq.ft.	D.m. per: sq. ft.: admitted	Remarks
RAPID GROWTH (3-6 mm. annual ring width)				
11	15	31.2	17	Strip 4" wide by 3' long killed and successful broods established. All other attacks pitched out. Tree not overcome.
12	15	46.4	10	Heavy attack on north side, but all pitched out.
15	18	50.0	10	All attacks unsuccessful.
18	14	44.0	11	Strip 9" wide and 10' long on S side with heavy brood developed to maturity. Remainder green.
MEDIUM GROWTH (Annual ring width 1.5 - 2.8 mm.)				
13	12	43.0	11.3	Strip kill including 1/2 of circumference on N and W sides with good broods.
14	12	23.0	13.1	All attacks unsuccessful.
16	16	51.0	10.0	" " "
19	14	36.0	14.0	Tree entirely killed. Heavy brood matured.
SLOW GROWTH (Annual ring width .2 - .9 mm.)				
7	12	43.0	7.0	Tree entirely killed; heavy brood developed.
9	10	28.0	11.0	" " " " " "
6	10	33.0	9.0	" " " " " "
8	10	28.0	12.0	" " " " " "

CONTROL METHODS

Control of mountain pine beetle infestations in sugar pine is limited by the season of the year, stage of brood, and bark thickness, and the success of any method is dependent on a working knowledge of each condition.

Burning

This method of control is most commonly practiced by the Forest Service and Park Service during the winter and early spring when the fire hazard is relatively low. Infested trees are felled, limbs removed, and the bark from the top half of the infested length is peeled. Bark and limbs are then piled along the lower sides of the log and set on fire, resulting in destruction of broods.

Suncuring and peeling

The large size of nearly all infested sugar pines with bark ranging from 4 to 6 inches thick in many instances, and the closeness of sugar pine stands precludes the effectiveness of suncuring, without peeling during the dry season when burning is impossible. By removing the infested bark, most of the broods are exposed to the elements, birds, and predacious insects, especially when younger stages predominate. A great many individuals in advanced stages of development mine into the bark a short distance and are thus protected against enemies. Knowledge of these conditions is essential.

Oil control

The use of oils against D.m. broods as a summer and autumn control method is a new development, still in the experimental stage. Briefly, the method consists in felling infested trees over a log, rock, or some object which raises the fallen log a few inches off the ground. Then oil is applied to the bark surface of the infested length by means of a pressure sprayer, the amount used governed by a thorough wetting of the bark.

The oil used is a product of the Standard Oil Company. It is a thin bi-product of petroleum distillation and with qualities enabling it to penetrate very readily into the bark. Used alone it is quite effective as an insecticide, but certain chemicals dissolved in it greatly increase its killing power.

In certain preliminary tests carried on in the summer of 1933, two formulae were used against D.m. broods in sugar pine, 21046/R and22458/R. Formula 21046/R had a measured amount of napthalene dissolved in the oil, while 22458/R contained a known quantity of crescylic acid, a derivative of phenol. The amounts of chemical in each formula are still withheld by

the Standard Oil Company as a matter of policy, since patents have not been applied for.

The results of one test presented in the table to follow is indicative of effectiveness and penetration after one week, of oil 21046/R, found to be most effective in all tests, but the amount of oil used is prohibitive under field conditions, not only because of cost but also transportation problems. Much smaller amounts have given as effective results when used against the western pine beetle in Ponderosa pine.*1

TABLE XII

Effectiveness of Oil Formula 21046/R

Log #	Bark thickness inches	Bark area sampled sq. ft.	Oil applied per sq. ft.	Dead Broods Larvae	Dead Broods Pupae	Dead Broods Adults	Living Broods Larvae	Living Broods Pupae	Living Broods Adults
1	.5	2.3	.050	142	9	0	3	0	0
Check	.5	2.6	----	2	0	0	79	48	48
6	1.0	2.0	.062	82	0	0	0	0	0
Check	1.0	2.0	----	3	0	0	44	8	4
13	1.5	2.0	.083	80	25	38	2	4	8
Check	1.5	2.0	----	0	0	0	26	19	31

Formula 21046/R was used on a D.m. control project in the fall of 1933, on the Sierra National Forest, *2 but it soon became obvious that its use must be governed by bark thickness and brood stages. The final results of the treatment will be determined by intensive examinations early in the spring of 1934.

Biological

The destruction of mountain pine beetle broods is accomplished in nature by various predacious and parasitic insect enemies and birds, but because of the physical handicap encountered by most of them of extremely thick bark the amount of D.m. control is minimized. In the writer's opinion, the clerid Enoclerus sphegeus Lec. is most important of any natural control factor. The larvae of this species are common under bark of any thickness.

*1---Struble, G. R. Preliminary Results of Oil Treated Ponderosa Pine Infested by D. brevicomis and Melanophila gentilis, Dec. 1933.

*2---Buell, C. R. Insect Control Report, Sierra N. F., Fence Meadow Project, December, 1933.

In this table some indication of clerid abundance is shown with winter and summer broods in 1932 and 1933.

TABLE XIII

Abundance of Clerid Larvae with D.m. Broods

Tree #	Broods	Sample #	Height from base	Area of Sample sq. ft.	Clerid larvae	Total D.m. brood
32/37	Overwinter	2	55	4	12	545
32/41	"	1	45	4	36	430
		2	100	4	21	830
33/6	Summer	2	48	2	14	252
33/7	"	1	40	2	62	869
33/8	"	1	12	2	9	389

Temnochila virescens, Aulonium longum, and Platysoma punctigerum are commonly found under the bark as well as many other predacious Coleoptera of lesser importance, but the extent of control they exert on D.m. broods is indefinite. Certain parasitic Hymenoptera are common in infested areas of thin bark, of which Coeloides sp. is most important. Parasitism of broods by this species in bark less than 1/2 inch thick is very high, but the occurrence of D.m. broods in thin bark is infrequent in sugar pine.

SECONDARY INSECTS

The insects included in this category are generally considered of secondary importance, since they are not aggressive unless a tree has been weakened by some other agency. Occasionally they are the cause of death or topkilling without apparent assistance of some other factor and considerable damage is done. Two species are important to sugar pine stands and must be recognized in the administration of control projects. They are the flathead borer, Melanophila gentilis, and a scolytid, Ips confusus.

Melanophila gentilis

This species is aggressive as a rule in the lower limits of the sugar pine range where the trees are generally in poor health and suffering from lack of water. Very rarely is it found to be the cause of death in the best stands of sugar pine, but when found there its attacks follow a weakened condition resulting from some other cause, usually D. monticolae. This species has a one-year life cycle and attacks occur throughout the summer months. Flathead work is recognized by flattened larval mines filled with borings between the bark and wood along the main trunk.

Ips confusus

The top portion of the main trunk and large branches of sugar pines are commonly invaded by this insect, following attacks of D.m., while infrequent invasions in the tops of green unattacked trees occur without the aid of another species. In the latter case the aggressiveness of Ips is apparently the result of large numbers built up to epidemic proportions. When aggressive attacks of Ips occur, sugar pines are weakened and are more susceptible to D.m. invasions, resulting in more rapid death. Arrested attacks of Ips resulting in red or snag top sugar pine are infrequent.

FURTHER STUDIES

Continued field studies on this problem are essential to determine questions still unsolved regarding life history and habits of the mountain pine beetle, the relation to the host sugar pine, studies of the most important predacious and parasitic enemies, and the improvement of summer control technic.

Problems are still unsolved regarding the extent of attacks made by re-emerged parent adults, a factor of great importance to the control of the mountain pine beetle. The determination of sex ratio and larval instars, although not important economically, is of scientific interest in rounding out this problem. The relationship between beetle and host needs further attention, especially the study of attacks made on mature trees.

Greater knowledge of the life cycle and habits of Enoclerus sphegeus, Temnochila virescens, hymenopterous and dipterous parasites is essential to determine their importance and to alter control technic for their protection.

A better knowledge of the effectiveness of summer control methods already practiced is essential. It is the writer's opinion that peeling alone is an effective method, but a futher knowledge of its efficiency is of great importance. Further studies with oils to determine effectiveness and penetration are necessary to round it out and determine its practicability.

SUMMARY

The prevalence of insect damage to sugar pine stands of the Central Sierra Region resulted in investigations which were conducted by the Bureau of Entomology during the fall of 1932 and summer of 1933 near Bass Lake on the Sierra National Forest. These studies revealed certain significant points as follows:

1. Surveys on 3 established sample plots which contain a high percentage of sugar pine over the past 4 years revealed that from 3 to 10 percent of the total volume had been killed. Ten percent is somewhat of an exaggeration for most stands of sugar pine.

2. On 47,096 acres of timber treated in spring control projects during 1933 on the Sierra National Forest and Yosemite National Park, 1,694 sugar pines with a volume of 9,948,060 board feet infested by D.m. and 2,617 ponderosa pines with a volume of 4,870,290 board feet infested by D.b.were treated by felling and burning. These figures point to the enormous size of sugar pines and the importance of protecting them.

3. Sugar pines are as a rule infested by the mountain pine beetle first in the top, and are finally killed after a succession of attacks extending down the trunk, over a variable period frequently as long as 2 to 4 years.

4. Two complete generations of D. monticolae are produced in the central Sierra Region. A partial third generation is developed if warm spring and fall weather prevails. Attacks are made along the main trunk and the tree dies as a result of egg channels and larval mines which girdle the phloem and cambium layers.

5. A small percentage of parent adults emerge when they have completed an attack, and fly to other green trees to cause further destruction. The extent and significance of this habit demand further consideration.

6. Statistical data on D.m.broods show great variation in abundance in different trees and in different stages of development. Brood counts made on trees killed in 1932 and 1933 contained broods varying from 100 to 120 to the square foot. The highest average count per square foot made on 12 square feet of infested bark area from one overwintering brood tree was 173.5 individuals and the lowest was 5.3 individuals from 2.6 square feet of bark from another overwintering tree. In the latter case heavy parasitism by Coeloides sp. was evident in thin bark.

7. The difference in temperature between the higher and lower elevation extremes of sugar pine has no appreciable effect on the development of D.monticolae broods. In an experiment conducted the rate of development in each case was nearly identical. Apparently the number of hours above the development point is most significant.

8. Growth rate is not a reliable index of trees selected by the mountain pine beetle. A comparison of 25 trees killed in 1932 with an equal

number of green unattacked trees of similar description showed no appreciable difference in growth. All showed a rapid decline in growth at the time D.m. attacks occurred. Slow growing trees are more easily killed, but even the most rapid growing trees will succumb provided there are enough beetles attacking them.

9. Control methods used against the mountain pine beetle in sugar pine are :(1) burning; (2) suncuring and peeling; (3) oiling. A certain degree of control goes on in nature by predacious and parasitic insects, the extent and importance of which demands further consideration. Burning is effective during the wet season, but the other methods must be studied further to determine their importance.

10. The flathead, Melanophila gentilis and the scolytis, Ips confusus, ordinarily considered to be of secondary importance, frequently become primary. Flatheads do considerable damage to sugar pines in the lower elevation limits of sugar pine. Ips frequently attack and kill the top and lateral branches of sugar pines without assistance, weakening and rendering them attractive to the mountain pine beetle.

Photo 1 (8551). Stand of sugar pine on west slope lying immediately south of Wawona Grove of Big Trees. Fading and red trees scattered throughout this stand are typical of the mountain pine beetle losses built up in sugar pine throughout the Central Sierra region in 1932. --Photo by J. M. Miller, August 18, 1932.

Photo 2 (8556). Large sugar pine near Grizzley Giant, Mawona Grove, infested in the top 25 percent of the crown by the mountain pine beetle. The foliage had turned sorrel at the time this picture was taken on September 7, 1932. This tree was cut on December 12, 1932 after the remainder of the crown had faded below the top killing. Broods were found to be in the larval stage from 25 feet below the original killing and in the egg stage for the balance of the trunk 20 feet above the base. The remaining 20 feet was comparatively free of attacks. -- Photo by J. M. Miller (Note figure of man standing at base on left side of bole. This gives by comparison an idea of the diameter and height of tree.)

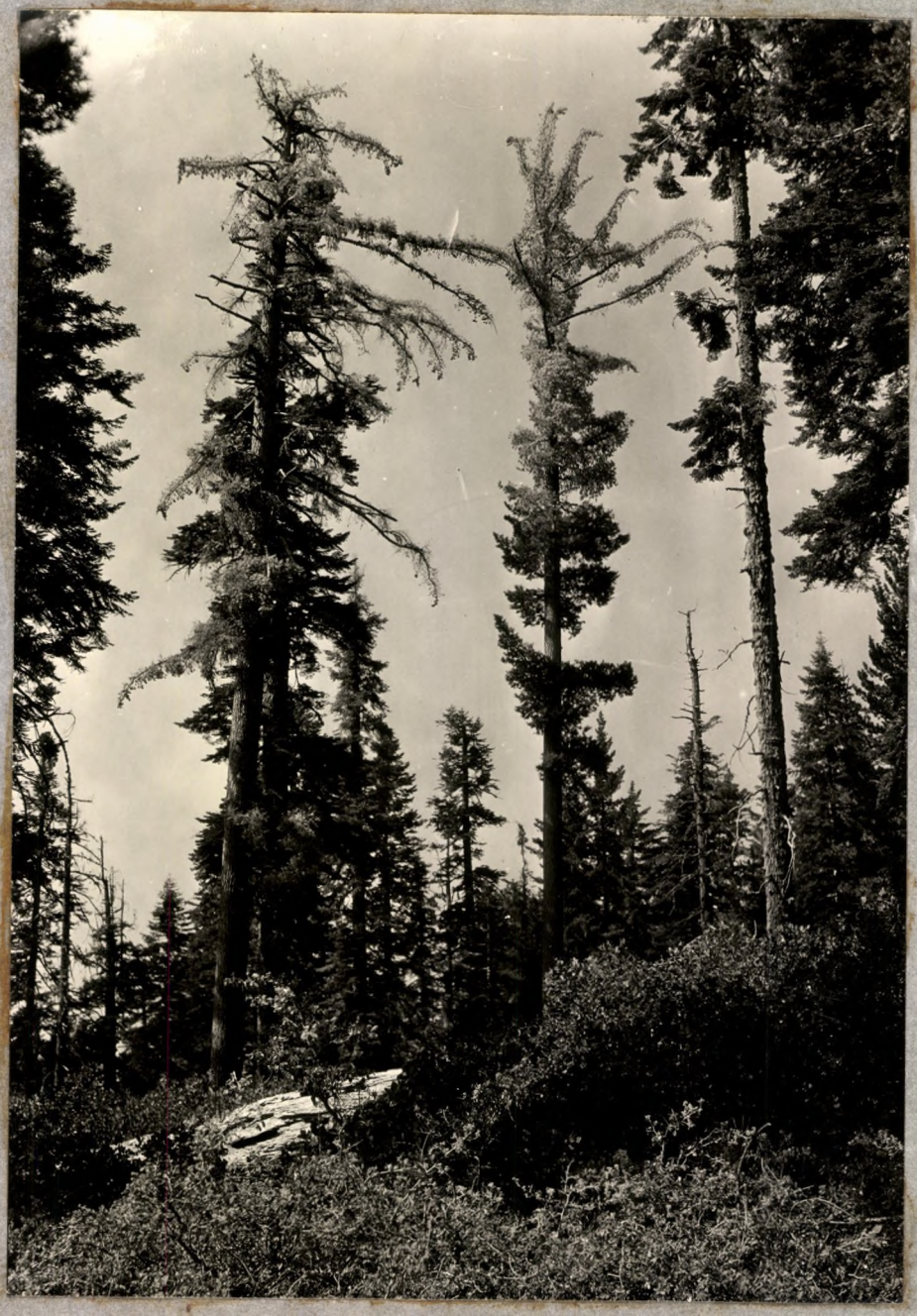


Photo 3 (8557). Sugar pines infested by the mountain pine beetle in General Grant National Park. The tree on the right is faded for more than 50 percent of the crown length, while the lower branches are green. The large tree on the left is completely faded sorrel. Dendroctonus monticolae adults were found to be emerging from the basal part of the trunk.
--Photo by J. M. Miller, September 11, 1932.

Photo 4 (28637). Group of snag sugar pines on White and Friant tract near North Fork, California. These were killed by the mountain pine beetle several years before this photo was taken. -- Photo by J. M. Miller, July, 1921.

Photo 5 (8404). Egg galleries of Dendroctonus monticolae Lec. resembling those of D. brevicomis, are frequently found in sugar pine. This attack is less than 10 days old. Parent adults were found constructing the galleries and laying eggs. Eggs are deposited in pockets excavated along each side of the gallery. Many of these pockets can be seen in the photograph. -- Original, July, 1933.

Photo 6 (8410). Two 8-inch sugar pines joined at the base. These were used in an experiment to determine whether parent adults emerged after a period, to re-attack other trees. Screen cylinder cages enclosed 10 feet of the base of each tree. Three hundred D.m. adults were admitted to the tree on the right. After two weeks, both cages were joined into one insect tight cage enclosing both trees. Only 5 attacks had been made by re-emerged adults on the tree to the left after a period of 2 months. All attacks made on both trees were successful and heavy broods were established. -- Original, Aug. 1933

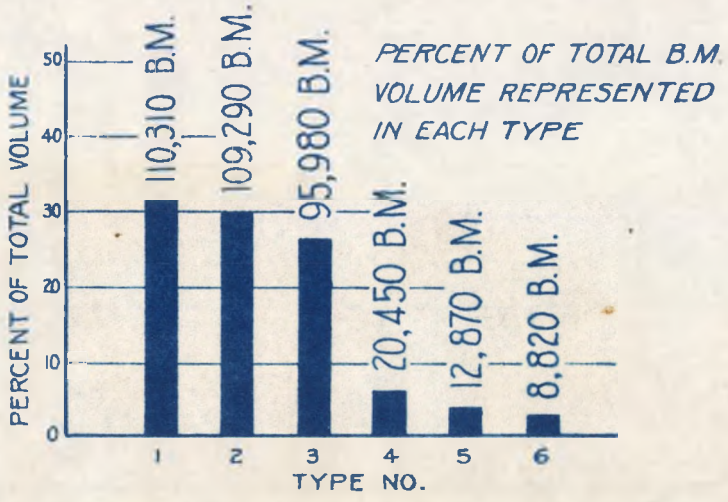
Photo 7 (8411). Egg galleries and larval mines of D. monticolae under bark more than 4 inches thick. Pupal cells are scattered among the mines. In bark of this thickness pupal cells are frequently constructed a short distance in the bark from the inner surface. -- Original, November, 1933.

FIG. 1

CLASSIFICATION OF INJURIES IN SUGAR PINE STANDS

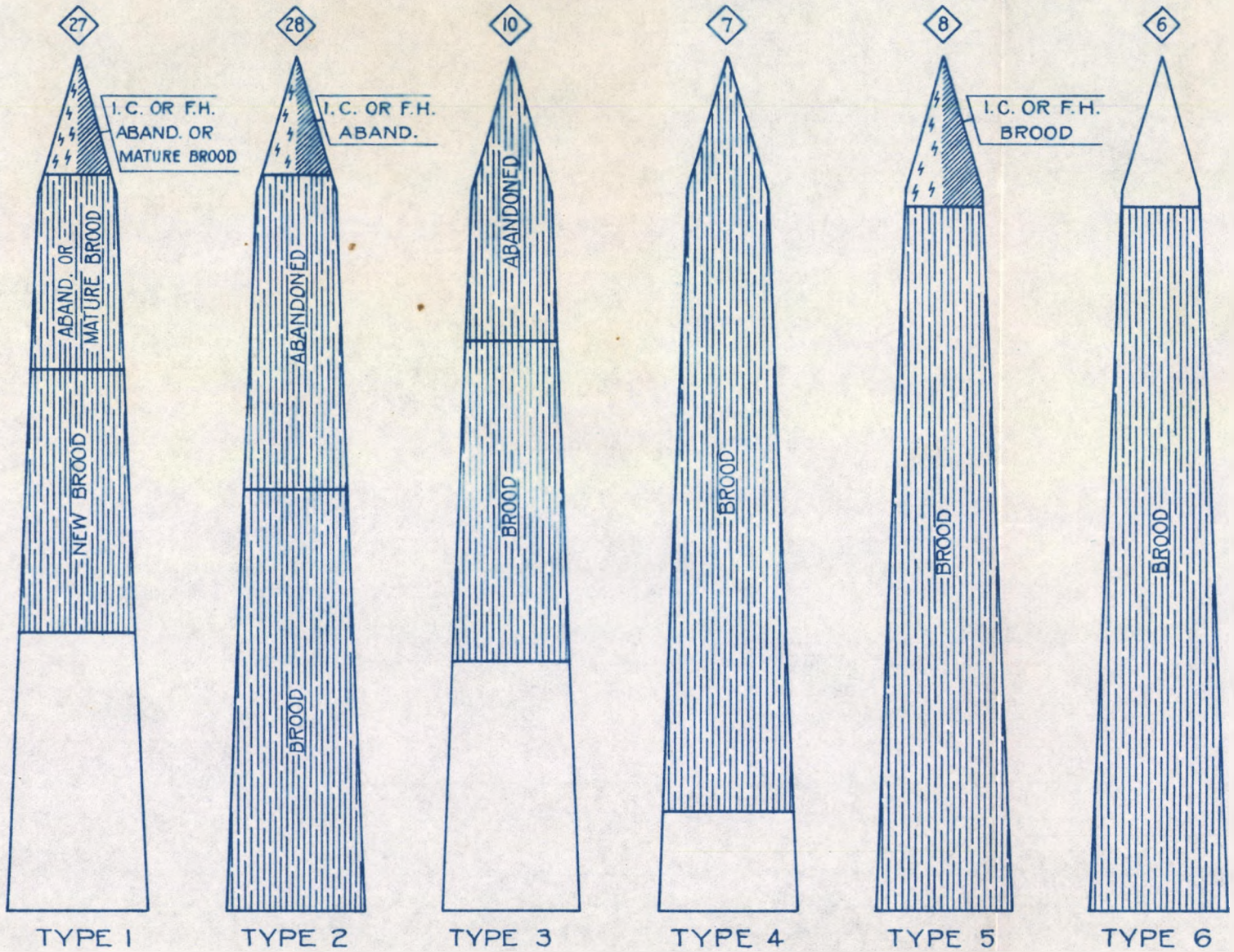
INFESTATION TYPES

BASIS 84 TREES



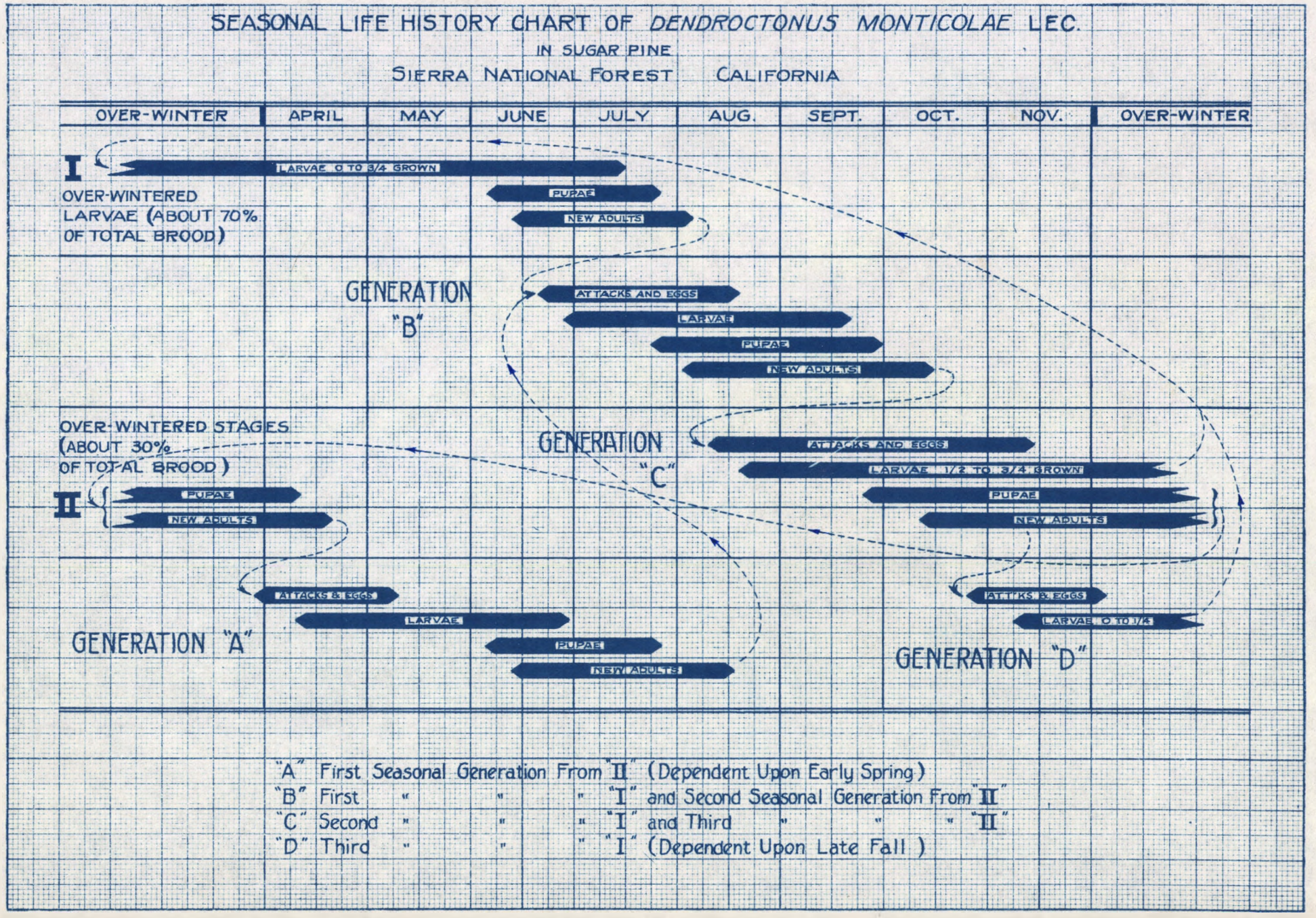
LEGEND

- DENDROCTONUS MONTICOLAE
- MELANOPHILA SPP. (F.H.)
- IPS CONFUSUS (I.C.)
- GREEN
- NO. OF TREES IN EACH TYPE



MATURE TREES 22"-84" DBH. — 100'-200' HIGH

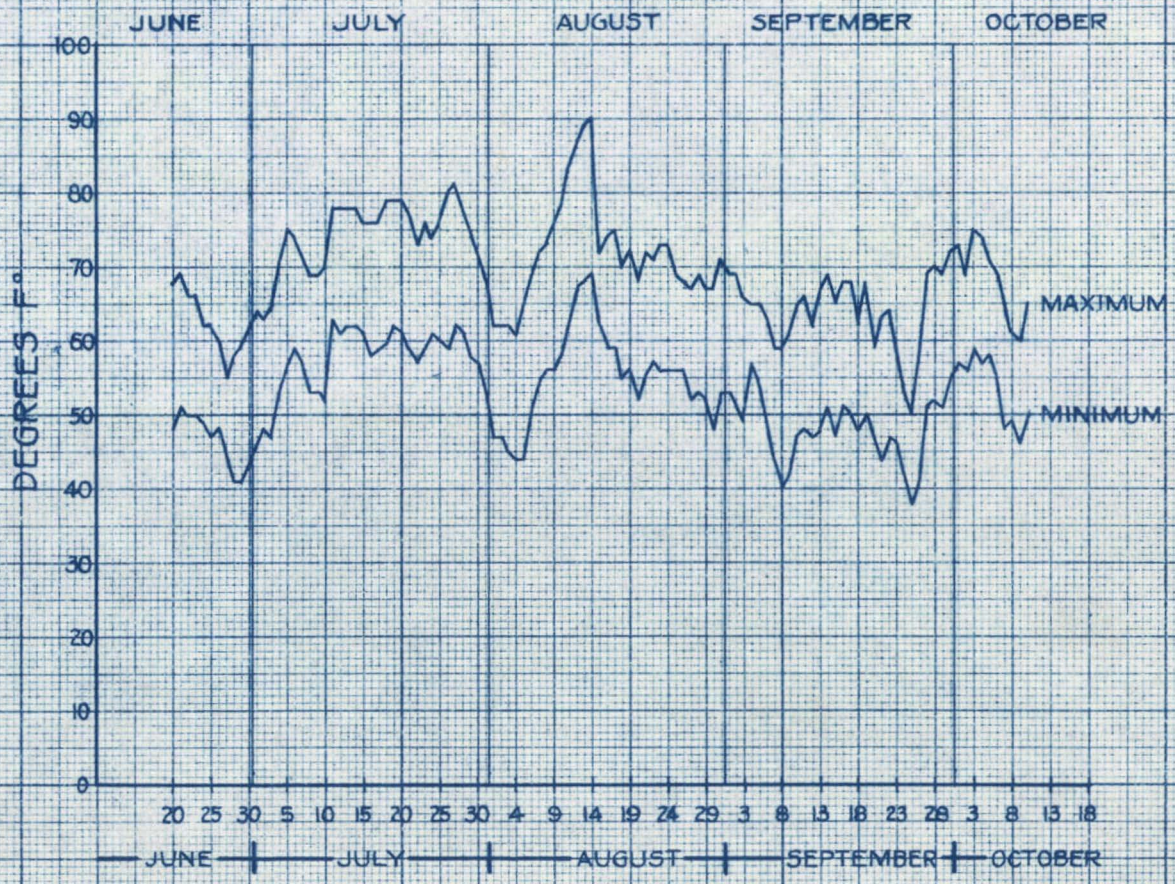
Fig. 2



"A" First Seasonal Generation From "II" (Dependent Upon Early Spring)
"B" First " " " "I" and Second Seasonal Generation From "II"
"C" Second " " " "I" and Third " " " "II"
"D" Third " " " "I" (Dependent Upon Late Fall)

FIG. 3

MAXIMUM AND MINIMUM TEMPERATURES
7000 FEET ELEVATION
NEAR
BASS LAKE
SIERRA NATIONAL FOREST, CALIFORNIA



1933

FIG. 4

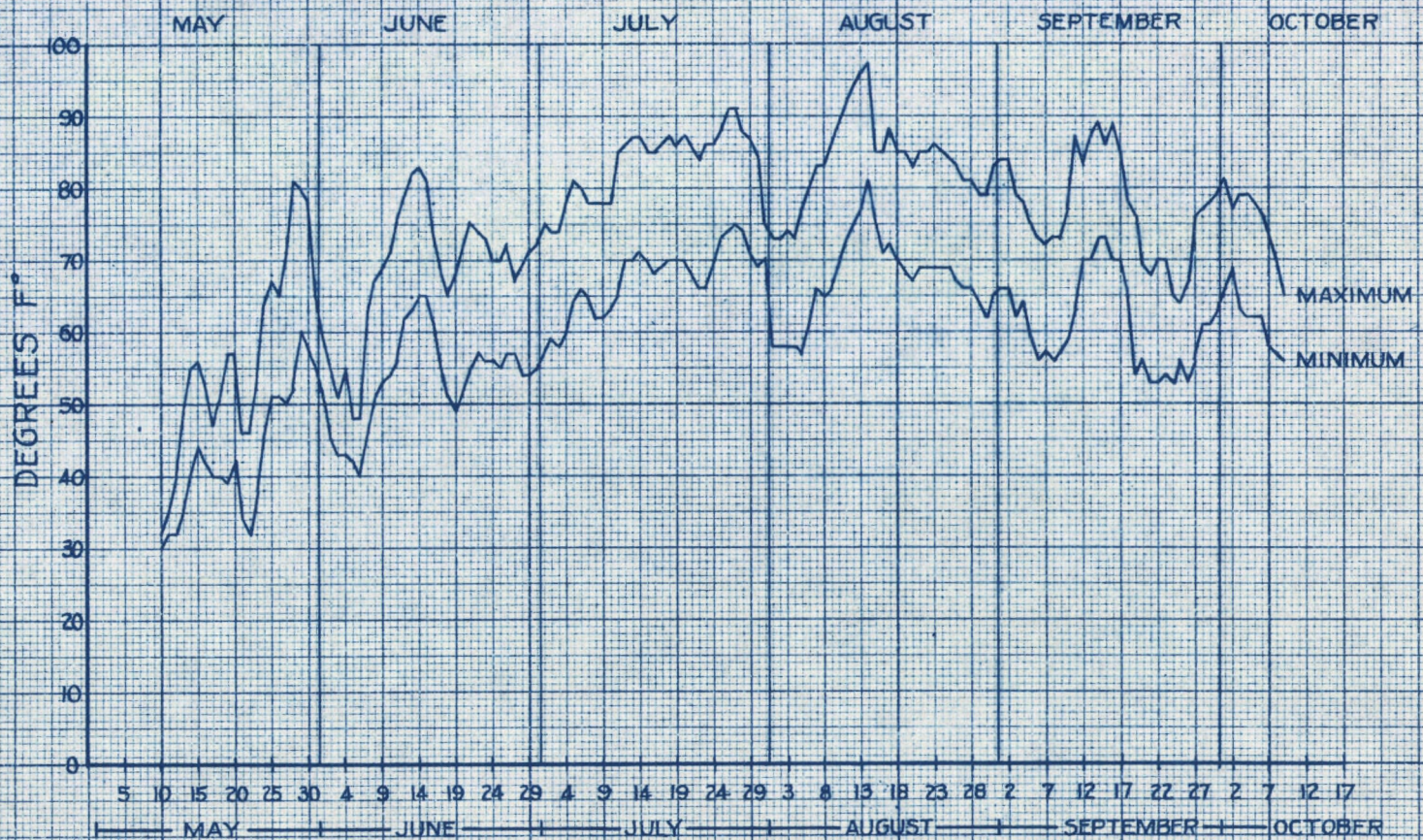
MAXIMUM AND MINIMUM TEMPERATURES

4200 FEET ELEVATION

NEAR

BASS LAKE

SIERRA NATIONAL FOREST, CALIF.



1933

FIG. 5

COMPARISON OF AVERAGE ANNUAL INCREMENT OF 25 D.M.- KILLED SUGAR PINES AND 25 GREEN CHECK TREES